Load Management in an Intelligent Office Building Using Model Predictive Control Strategy

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Intelligent Energy Systems

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Outline

- Introduction
- **SYSLAB**-Distributed Power System Platform
  PowerFlexhouse-Intelligent office building
- Model predictive controller
- Results
- Future work
- Conclusions

Introduction: Power Systems with high penetration of Wind

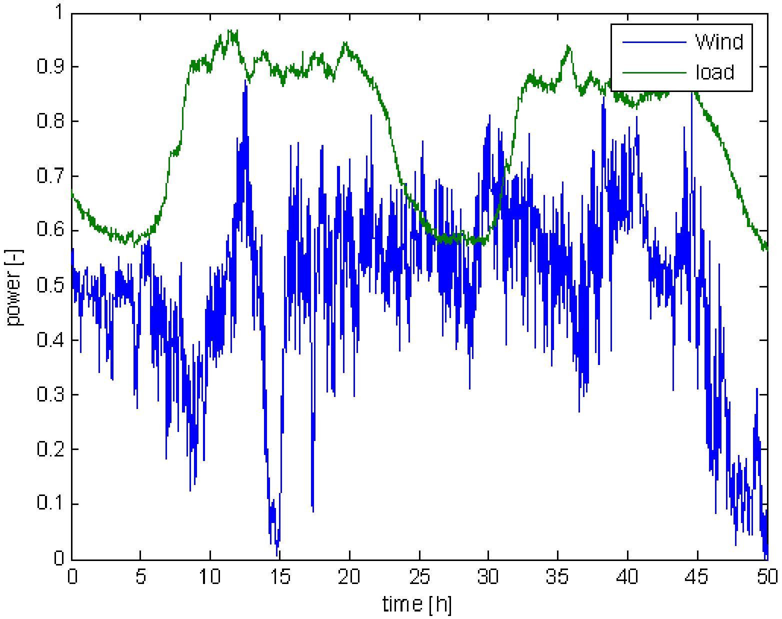


Fig. 1. Load and wind power variations

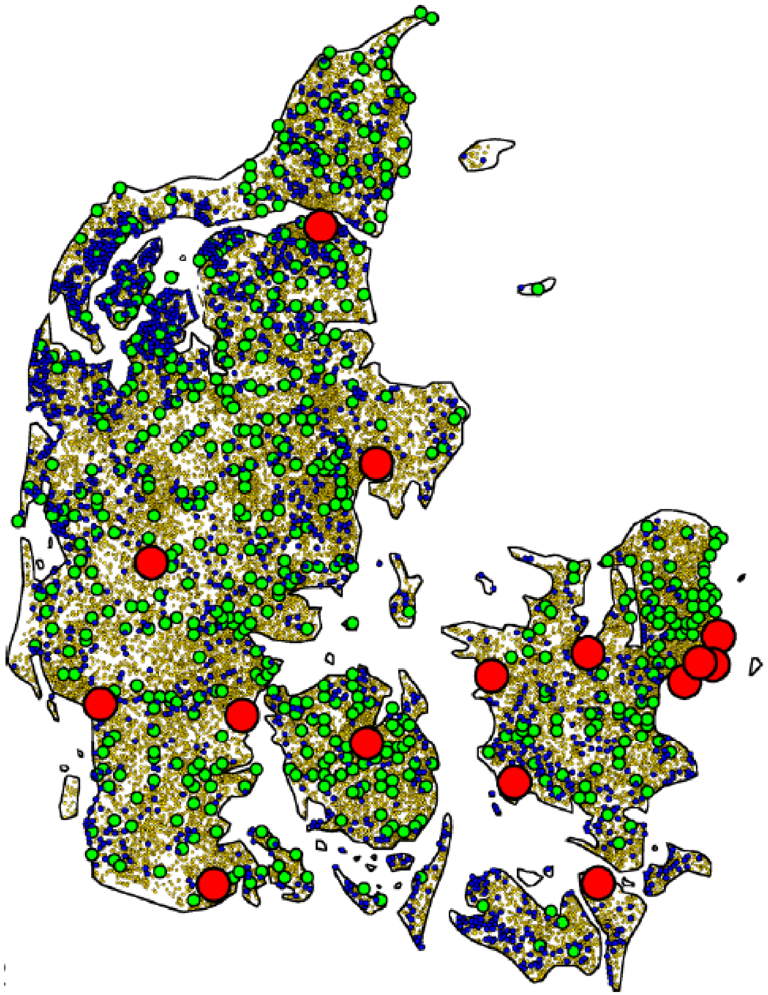
Integration of **50%** wind energy into electricity system by 2025 in Denmark

Issues with wind
- Fluctuations
- Variations
- Predictability

Production  **Consumption**

Flexibility can be provided by several means:
- Supporting grids (Transmission / Production)
- **Flexible/intelligent consumption –Time shifting**
- Energy storage

Introduction: Distributed Small Energy Resources

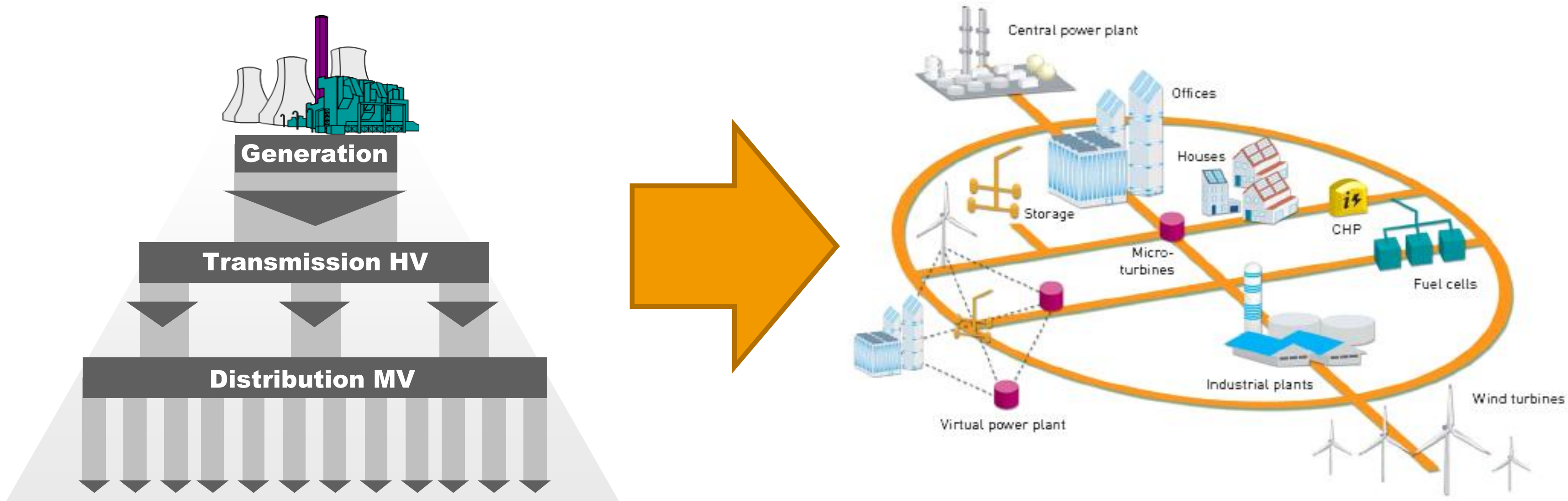


Year 2025:

- 15 central power plants
- 500 local CHP plants
- 6.000 wind turbines (50% of energy)
- 1.000.000 small energy resources (households, electrical vehicles, industrial consumers)

- Distributed small energy resources need to participate in the provision of ancillary services.
- **Active** load management
- Energy efficiency

Challenges of the Future Energy System



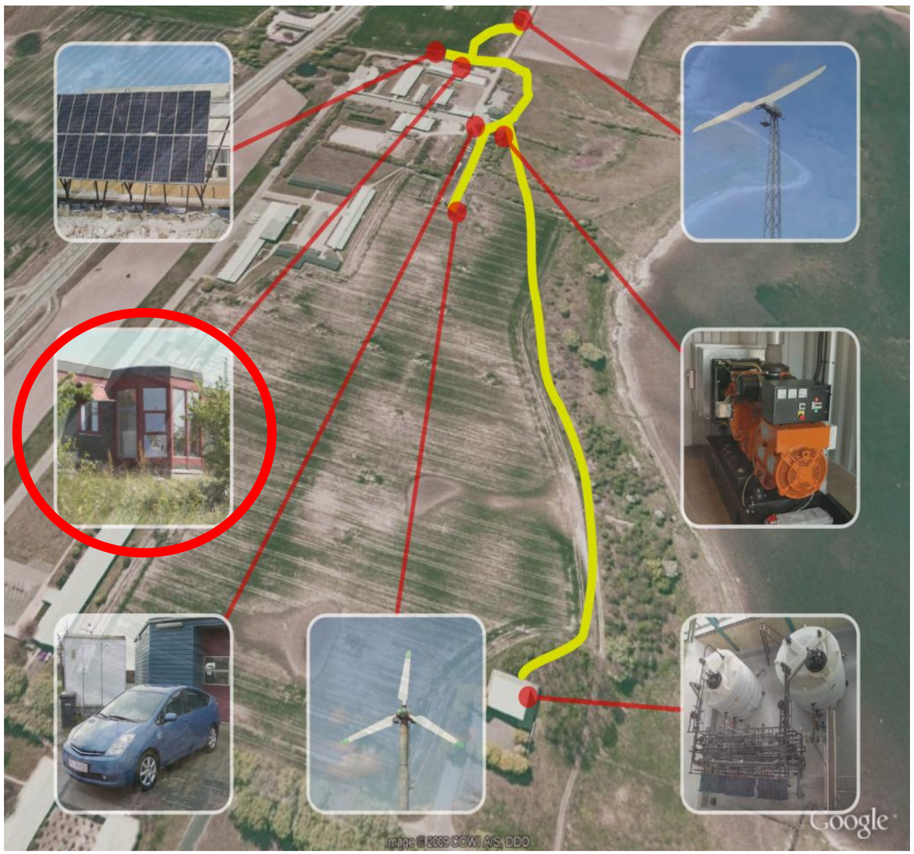
Present Energy System

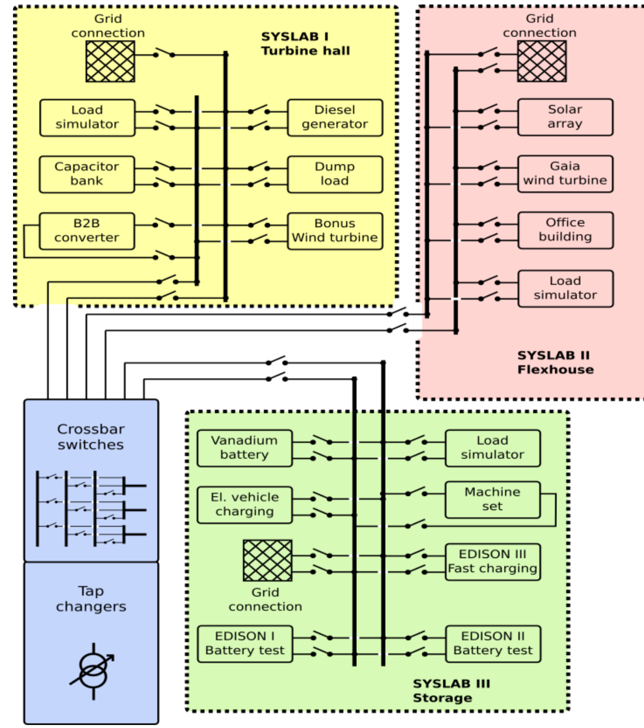
- Production follows load

Future Energy system:

- Consumption follows production

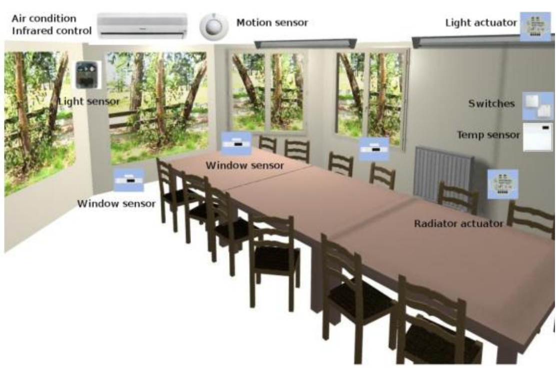
SYSLAB-Distributed Power System Laboratory

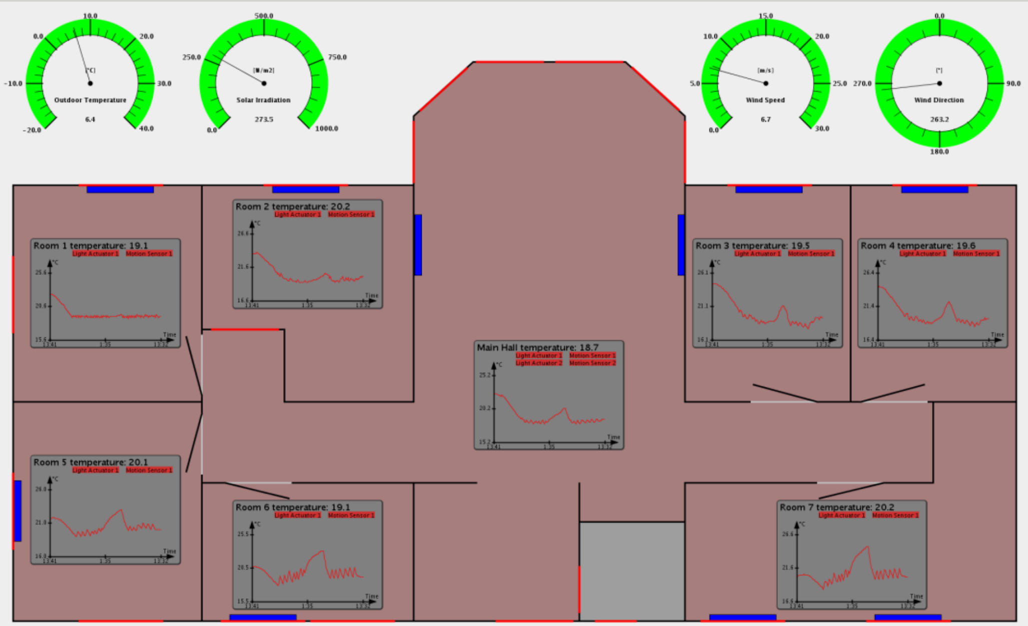




PowerFlexhouse-Intelligent office building

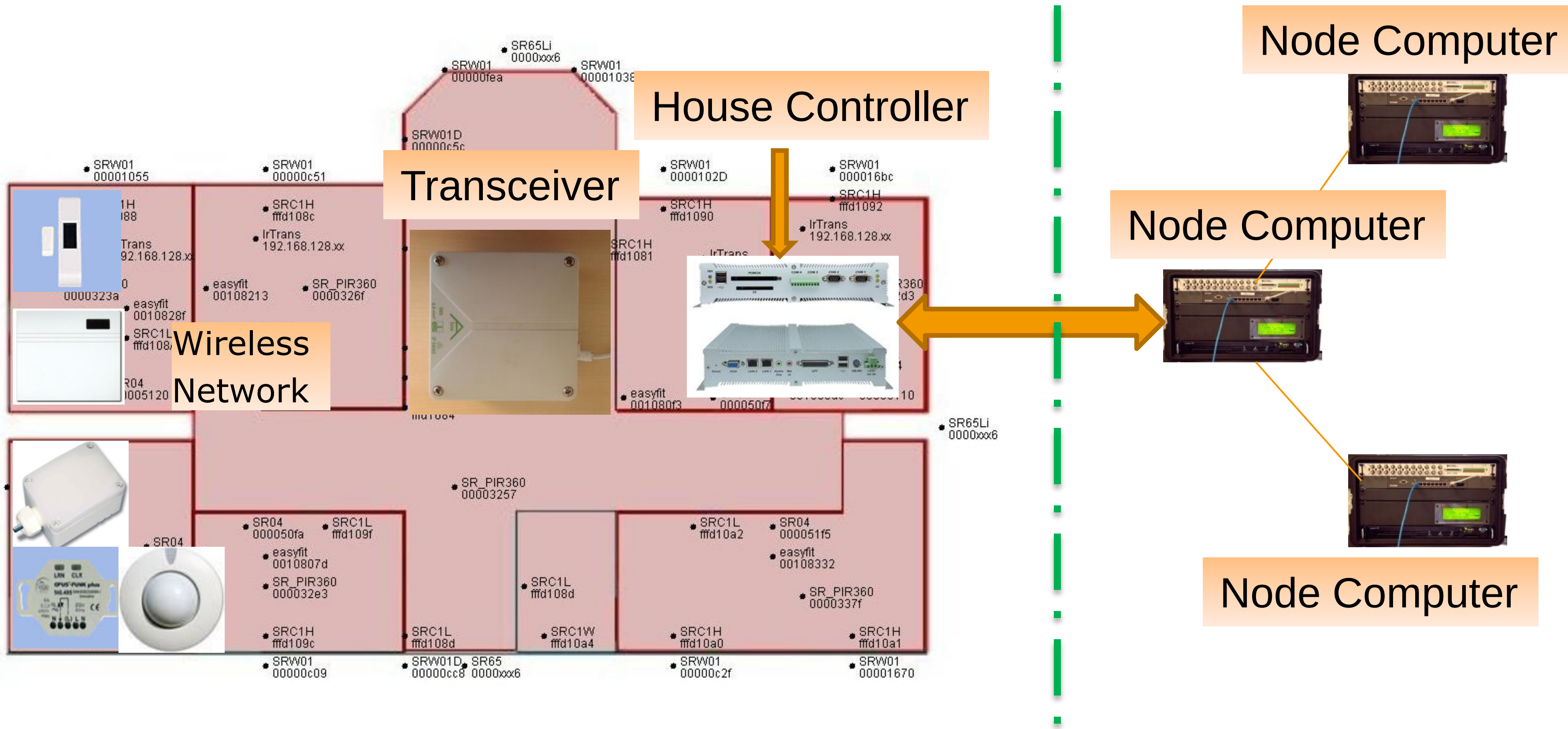
- Active load management
- Many individually controllable loads
  - Heaters
  - Air conditioners
  - Water heater, coffee machine, etc.
- Many sensors
  - Motion
  - Temperature
  - Door/Window
  - Solar irradiation
  - Wind speed
- Actuators and switchers, etc.





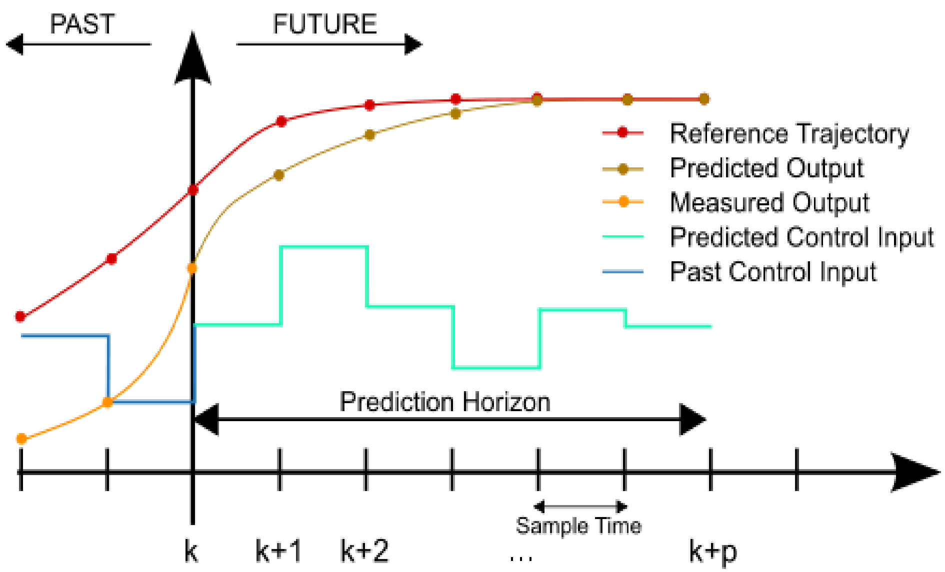
Hardware Infrastructure

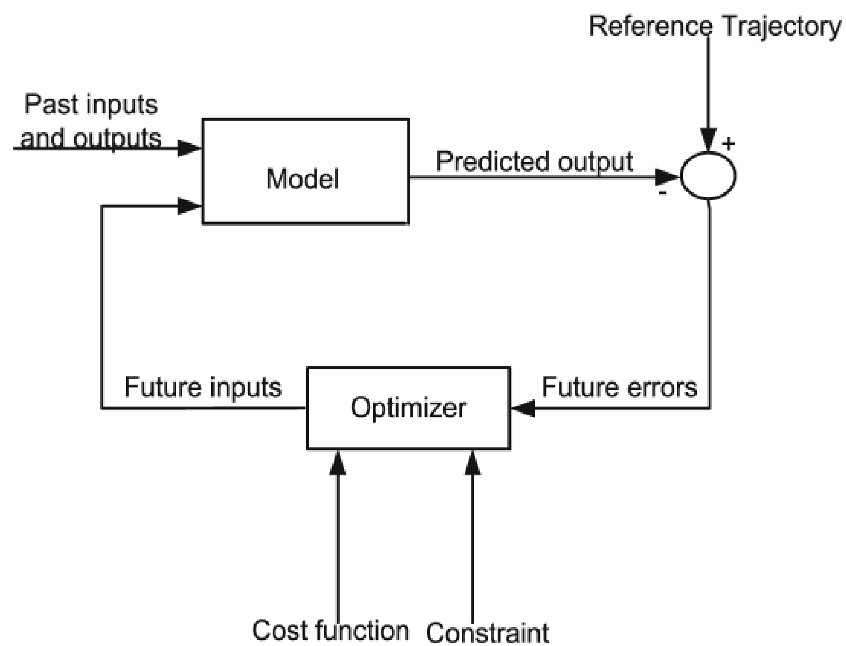
- PowerFlexHouse
- SYSLAB Network



What is Model Predictive Control ?

MPC refers to a class of control algorithms that compute a sequence of manipulated variable adjustments to keep the reference trajectory by utilizing a process model to optimize forecasts of process behaviour based on a linear or quadratic open-loop performance objective, subject to equality or inequality constraints over a future time horizon.



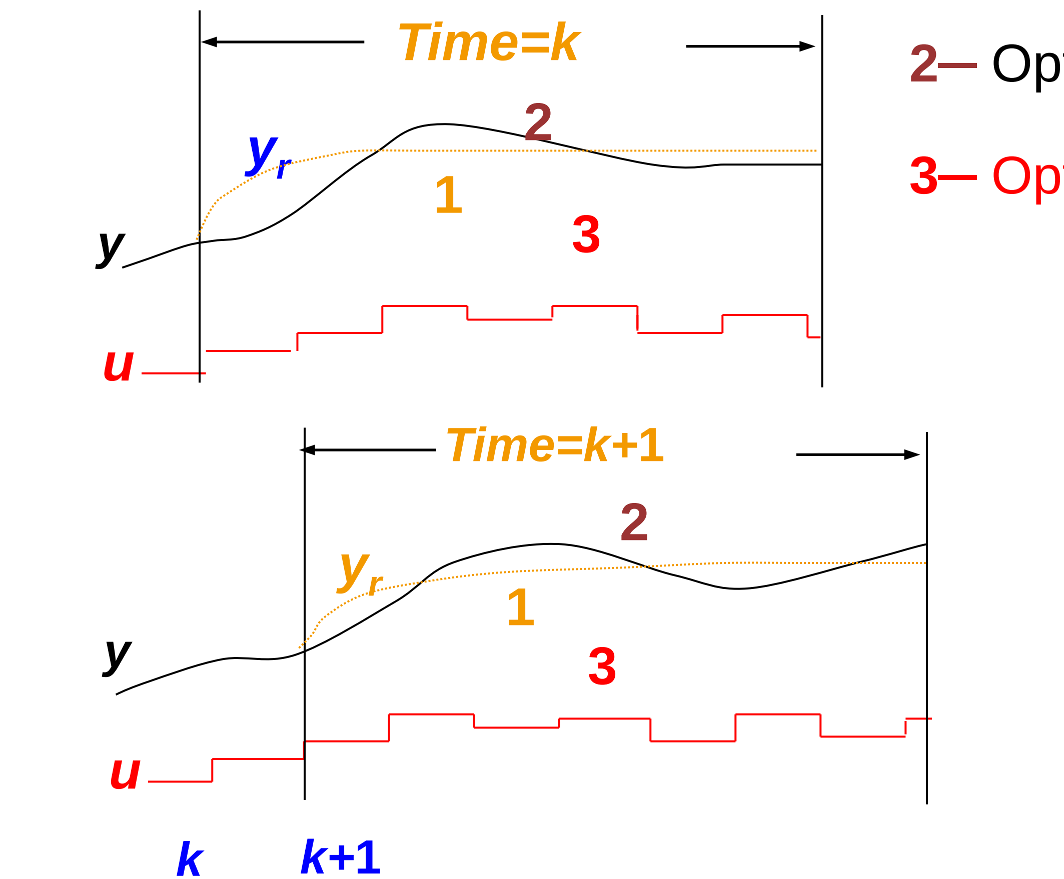


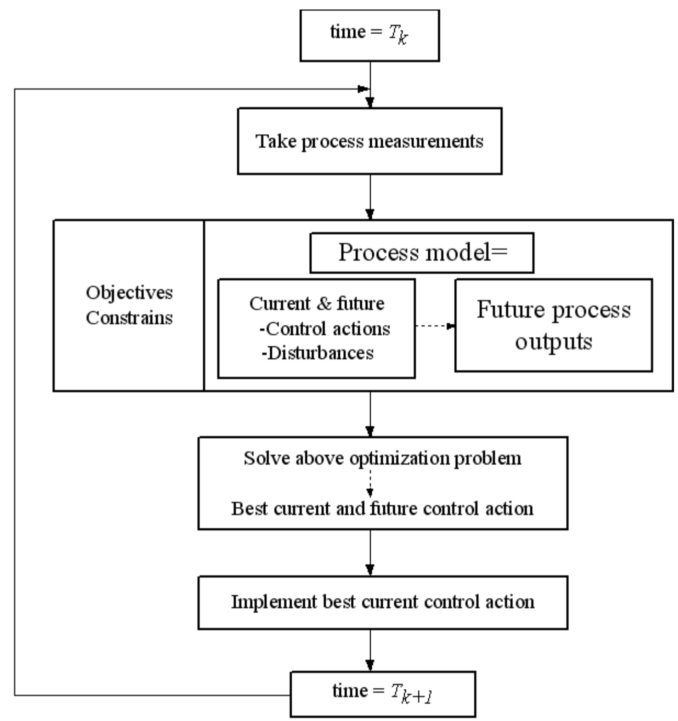
MPC Strategy=Receding Horizon Control

1– Reference trajectory y_r

2– Optimal predictive output y

3– Optimal control action u

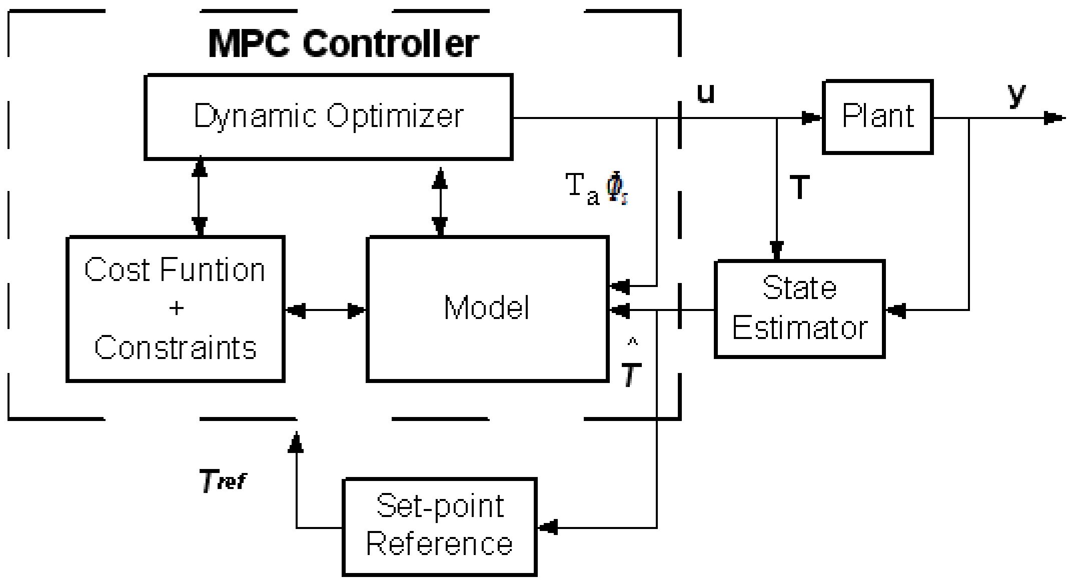




Model Predictive Controller (MPC) for Flexhouse's Heaters—Load shifting

Components of MPC

- Prediction model
- Objective function
- Obtaining the control law



Discrete-time linear state-space model
[Anders Thavlov]

$$\boldsymbol{T}(t+1) = \Phi\boldsymbol{T}(t) + \Gamma\boldsymbol{U}(t) \qquad (1)$$

Output: $$\boldsymbol{y}(t) = \boldsymbol{C}\,\boldsymbol{T}(t) = [1\ 0\ 0]\begin{bmatrix} T_i(t) \\ T_{im}(t) \\ T_{om}(t) \end{bmatrix} \qquad (2)$$

where

$$\Phi = \begin{bmatrix} 9.9288\times10^{-1} & 1.8661\times10^{-4} & 5.6429\times10^{-3} \\ 2.7410\times10^{-1} & 7.2489\times10^{-1} & 8.1923\times10^{-4} \\ 1.5641\times10^{-4} & 1.5459\times10^{-8} & 9.9649\times10^{-1} \end{bmatrix}$$

$$\Gamma = \begin{bmatrix} 1.2844\times10^{-3} & 2.9990\times10^{-2} & 1.0226\times10^{-2} \\ 1.8592\times10^{-4} & 2.6053\times10^{2} & 1.4838\times10^{-3} \\ 3.3551\times10^{-3} & 1.6128\times10^{-6} & 8.0402\times10^{-7} \end{bmatrix}$$

$\boldsymbol{T}=[T_{in}\ T_{im}\ T_{om}]$ is the state vector and $\boldsymbol{U}=[T_a\ \Phi_s\ \boldsymbol{\Phi_h}]$ is the input vector to the system.

Objective function

$$J = \min \left[\sum_{k=0}^{H_p-1} C(k) \times \mu(k) + \sum_{k=0}^{H_p-1} w\left(\left|T_{in}^{k} - T_{ref}\right|\right)^2\right]$$

- Constrains:
  - minimum indoor temperature T_{in_min} =19.5 ℃
  - maximum indoor temperature T_{in_max}= 22.5 ℃
  - reference indoor temperature T_{ref}= 21.5℃

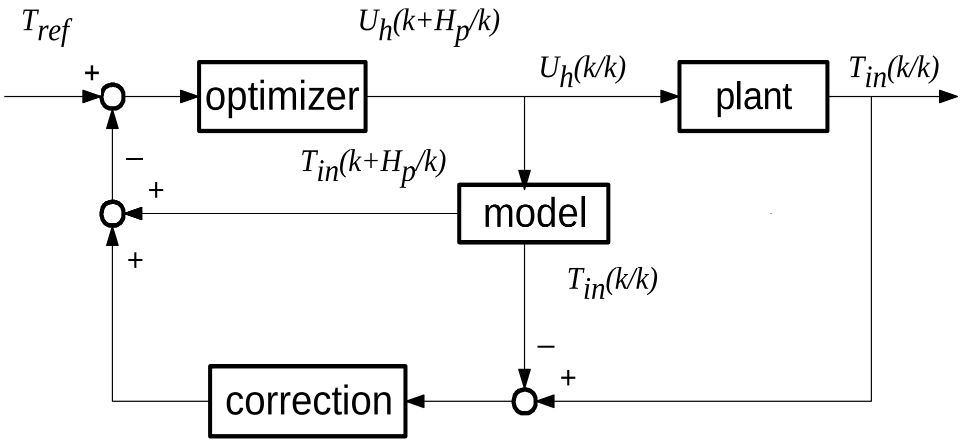
C(k) is the dynamic power price signal.

μ(k) ϵ int [0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10],*which means the heat inputs that the MPC heat controller determines by **mixed integer optimization approach.***

$$\begin{aligned}
&\min_{\Delta\mu_0,\dots,\Delta\mu_{N-1}} \sum_{k=0}^{N-1} \|C_k \Delta\mu_k\|_p + \left\|w(y_k - y_{ref}\right\|_p \\
\text{s.t.}\quad & x_0 = x(0) \\
& x_{k+1} = \mathrm{A}x_k + B\mu_k \\
& y_k = Cx_k \\
& x_k \in X \\
& y_k \in Y \\
& \mu_k \in U
\end{aligned}$$

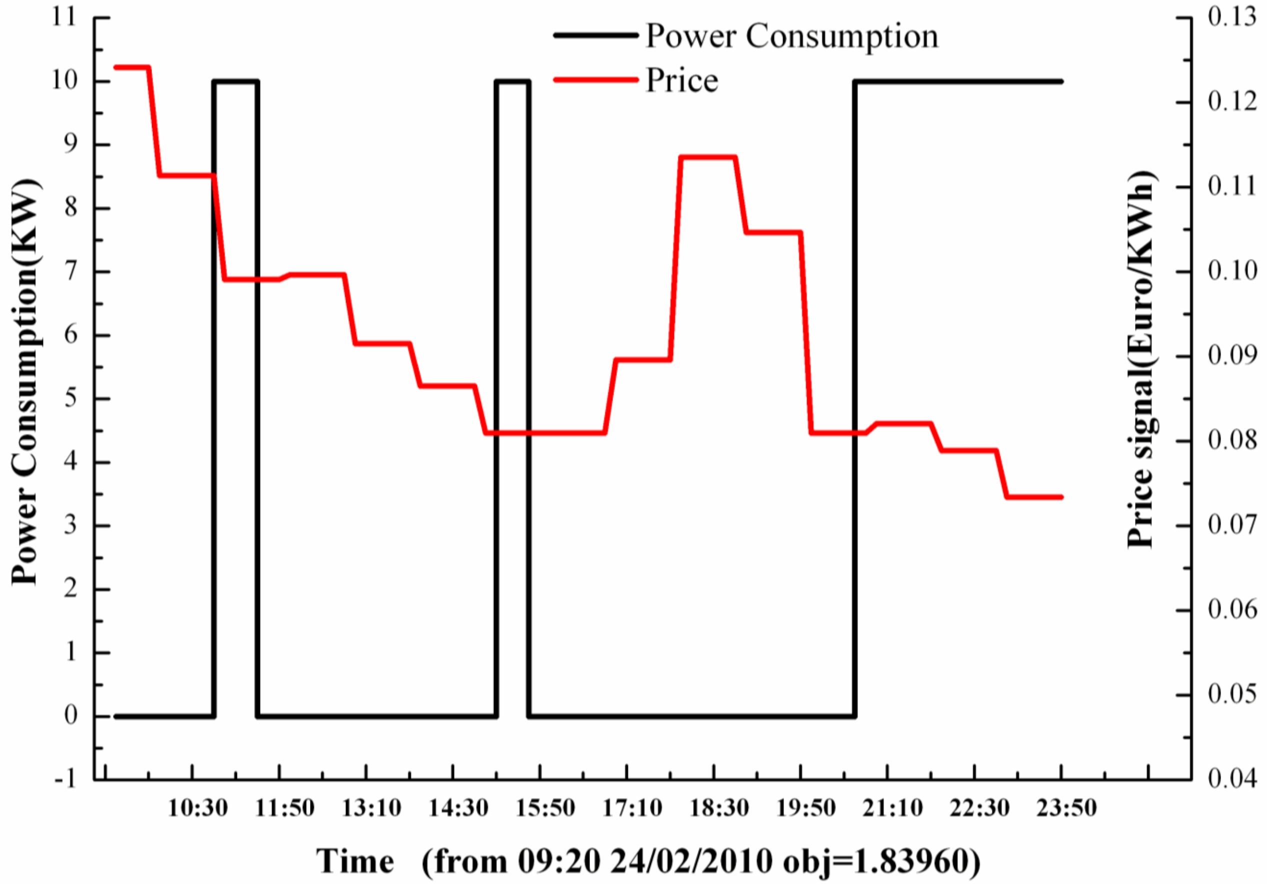
Tools

- Dynamic power price signal: http://www.nordpoolspot.com/reports/systemprice
- ***GNU Linear Programming Kit (GLPK Java)*** *ver 4.39*
- *Java Matrix Package:* ***JAMA***



Results: no weather forecast data

- Optimized predictive power consumption for the next 15 hours



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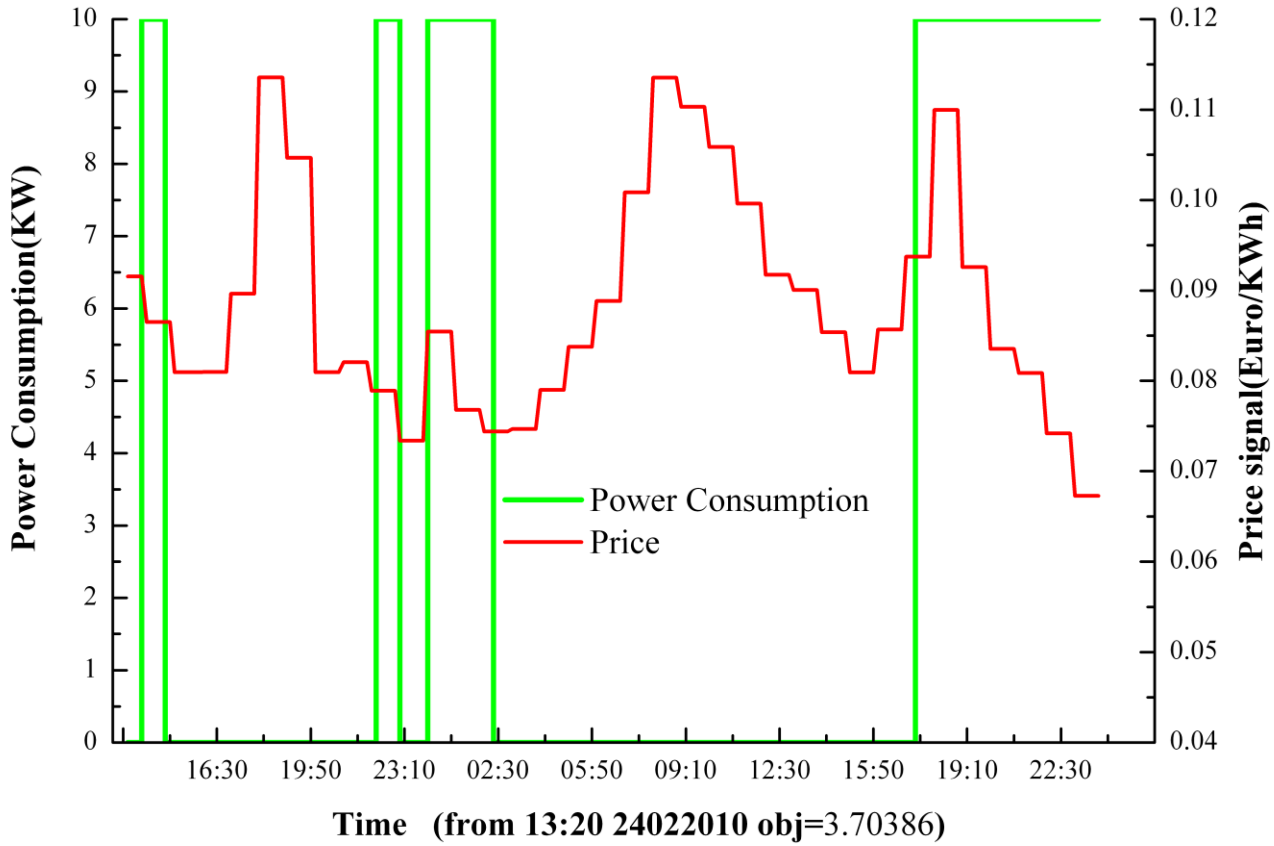
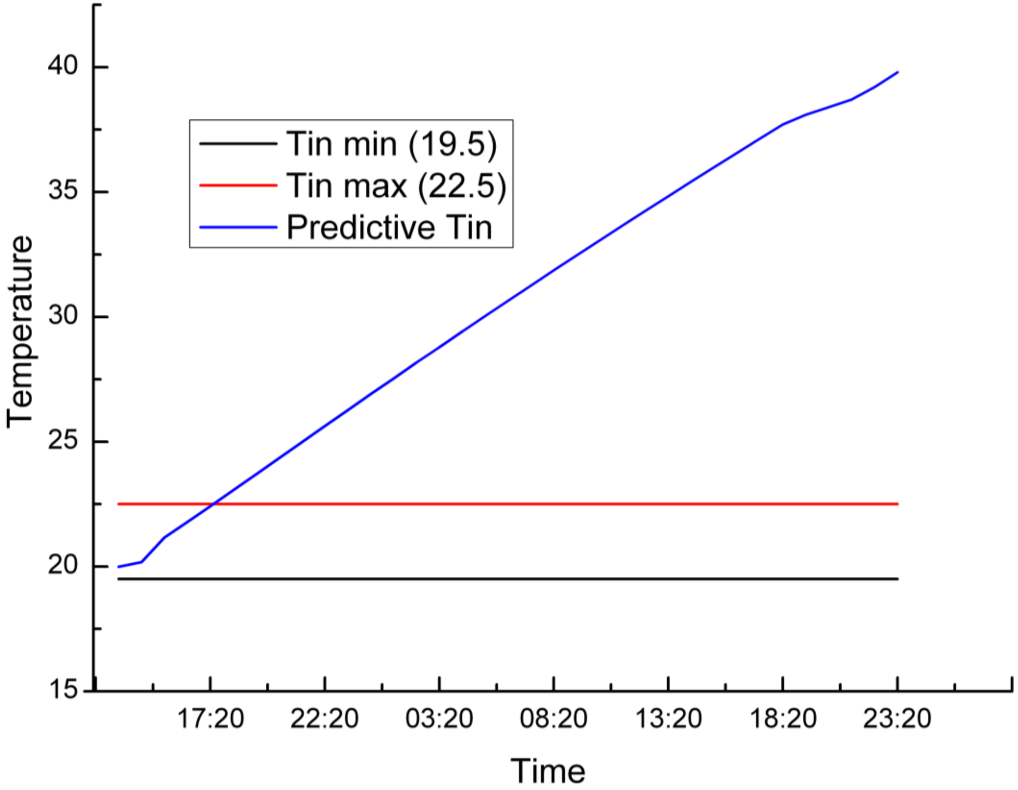
Results: no weather forecast data

- Optimized predictive power consumption for the next 35 hours



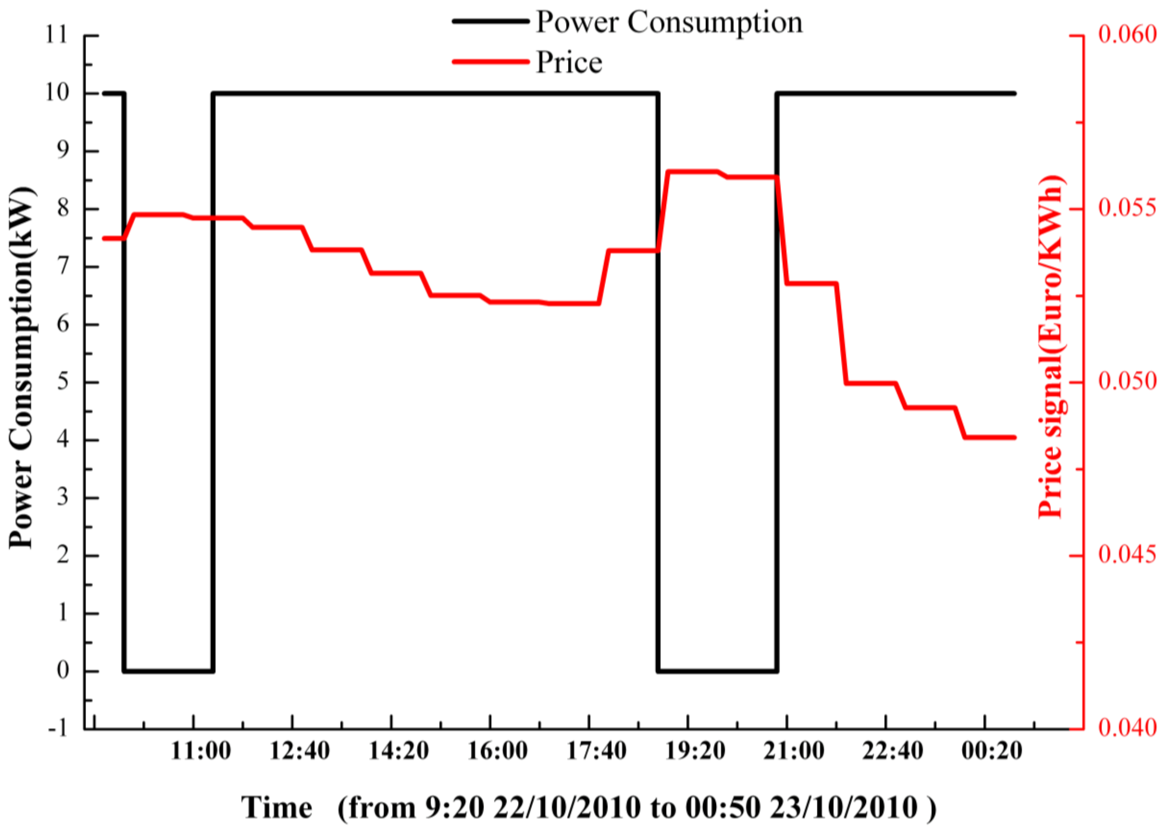
MPC: model??

- Predictive Temperature ???



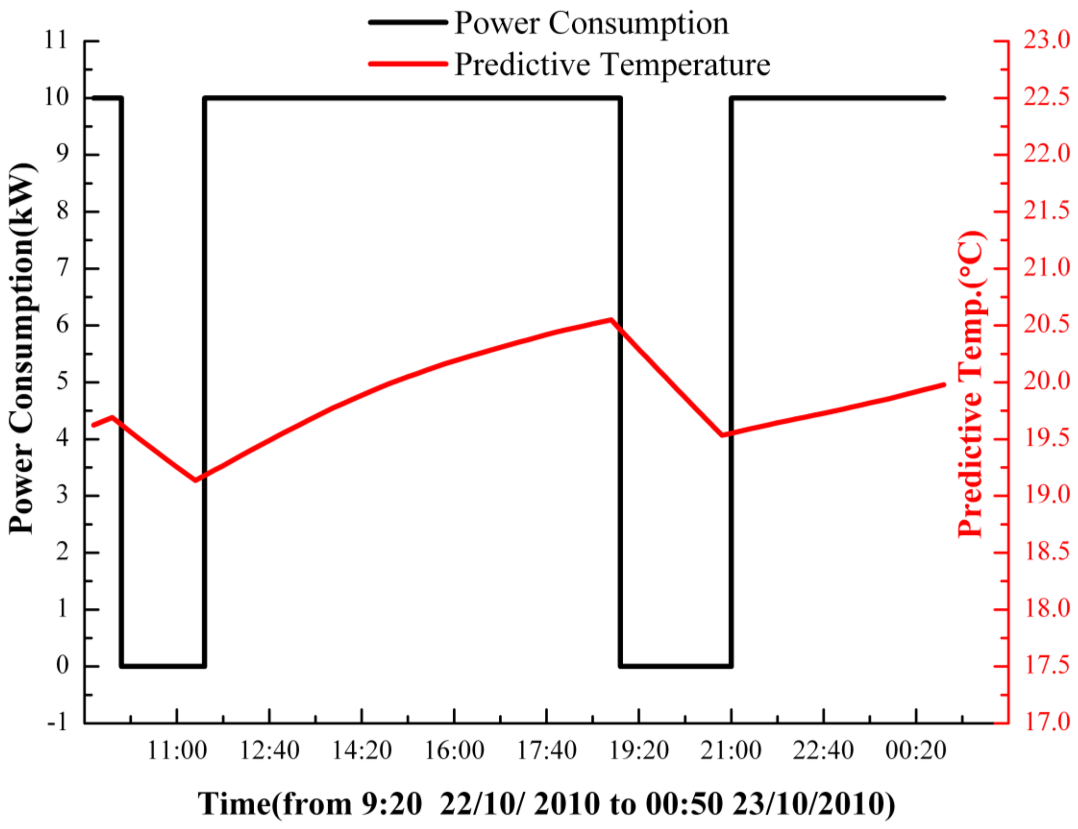
Results: Integrate VEA weather forecast data

Optimized predictive power consumption in the next 15 hours



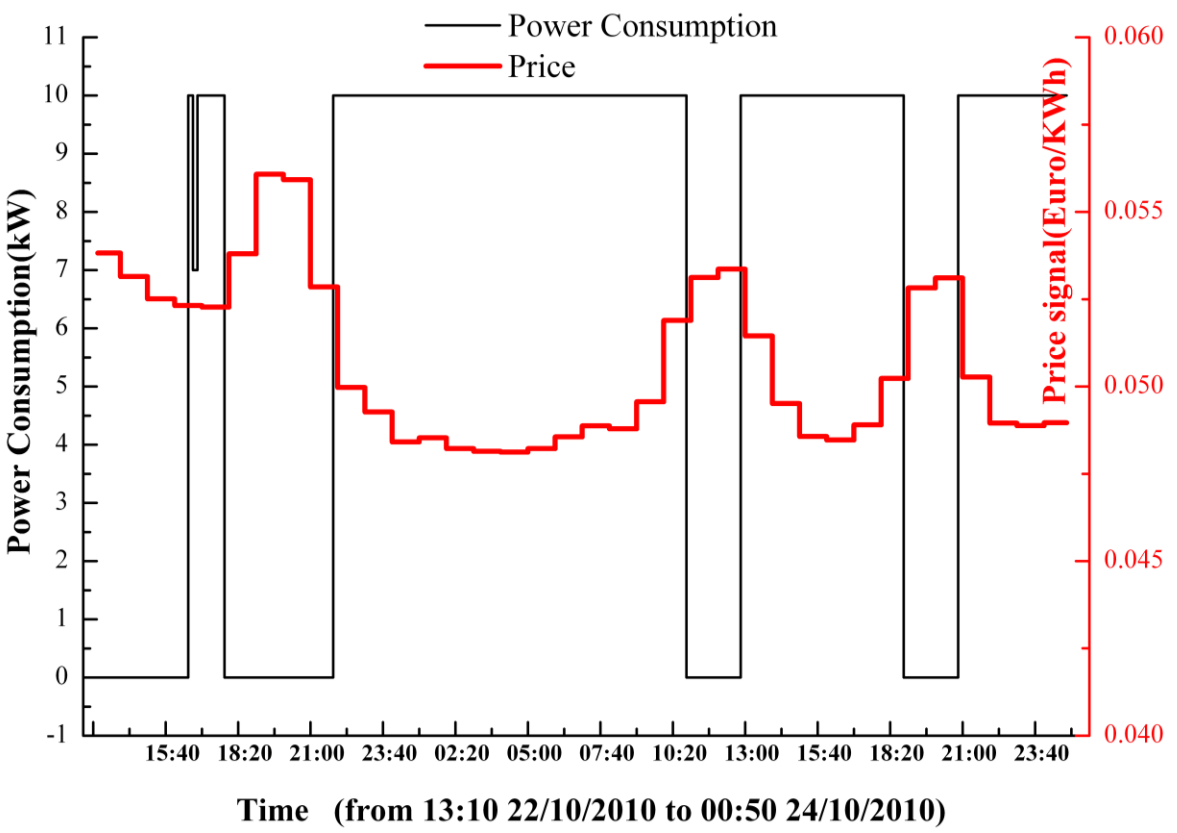
Results: Integrate VEA weather forecast data

Predictive inside temperature in the next 15 hours



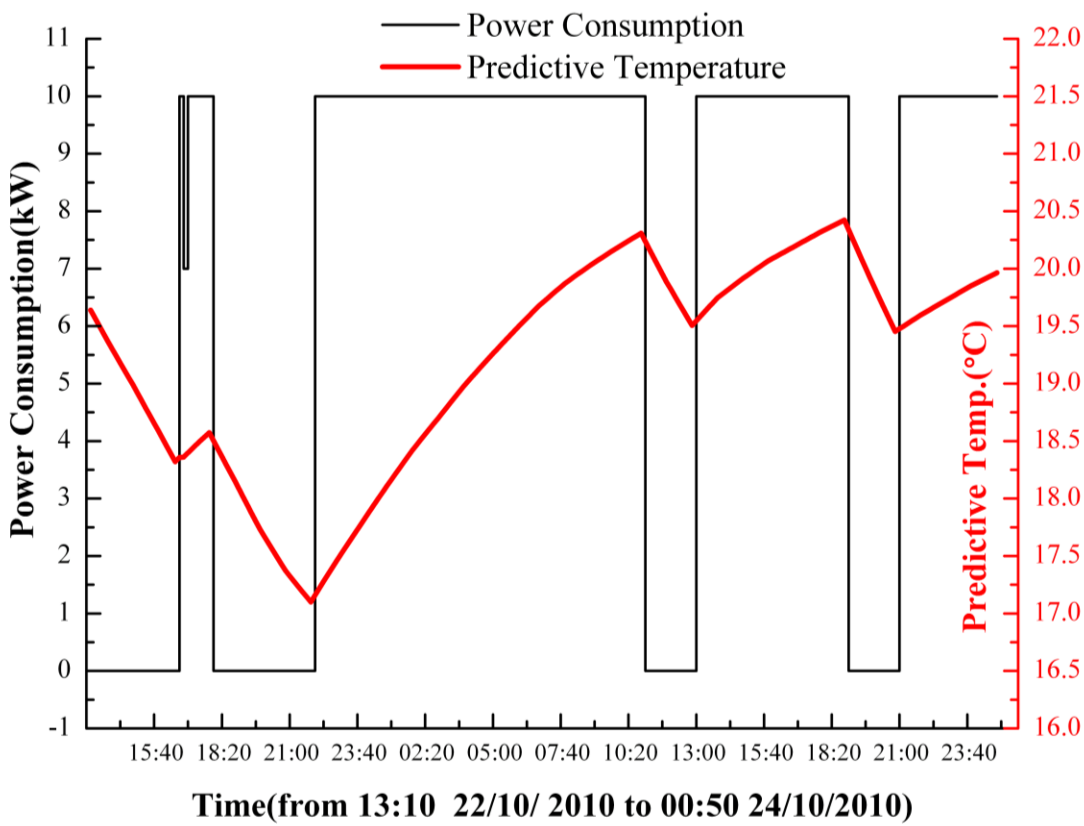
Results: Integrate VEA weather forecast data

Optimized predictive power consumption in the next 35 hours



Results: Integrate VEA weather forecast data

Predictive inside temperature in the next 35 hours

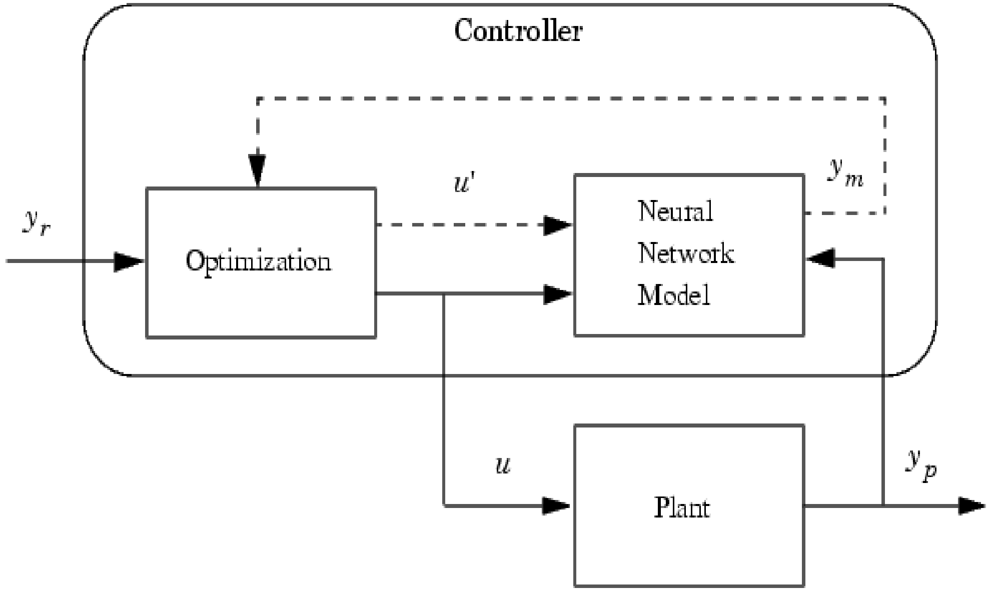


Future work

- Comparison with different control strategy (thermostat operation)
- User Interface
- Nonlinear optimization

    Objective function / Quadratic optimization

    NN Predictive Control for nonlinear model



Conclusions

- It is clearly demonstrated that the MPC strategy is feasible for load management of intelligent houses in a distributed power system with high wind penetration.
  - The predictive control effect depends on the prediction horizon.
  - Model plays a very important role.
- It also shows that various control strategies and theories can be investigated on load management and also on how this intelligent house, which is used to stabilize fluctuations in the power grid with a high penetration of renewable energy, in comparison with the actual power system presented within the SYSLAB.
- The load in a power grid is widely seen as one of the keys to achieving additional operational flexibility to ensure the stability of the grid as penetration levels rise. However, the efficient use of load management demands a tight integration with the control system of the power grid.
- Residential customers can avoid high electricity price charge at peak time, and the power grid can benefit from load control.

Acknowledgement

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Thank you!

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